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Performance Profiles of Collegiate and Master's Swimmers: A Validation Study

Lyle E. Robelot Mr.

Performance Profiles of Collegiate and Master's Swimmers: A validation study

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Lyle E. Robelot

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ABSTRACT

The purpose of this proposal is to link the gold standard power test on land (Wingate test) to an in-water power test. There is a lack of information on power in the water and would be beneficial in tracking swimmers progress throughout a season and between seasons. Power curves of individuals on the Wingate test will be compared to those of In-water tests to see weather this water test is valid. The experiment will follow IRB rules and regulation and the staff will adhere to the safety conditions set forth by the IRB.

CHAPTER 1: LITERATURE REVIEW

Power is defined as the rate at which work is done. In swimming, power is critical to high performance. Collegiate swimmers perform resistance training in the water as part of their normal training regimen. Although studies in the past have investigated power training in the water, no waterpower test exists to compare power on land and water. A genuine need to standardize a way to test power in the water that is relatable to the results of the Wingate power test exists. Elements of an in-water power test and the Wingate test will be compared and contrasted. The type of swimmer and sex of the swimmer will most likely effect the rate of power decay of the Wingate test and the in-water test. The Current Power Training apparatus, the physiology and waste products of swimmers, research on resistance and power training, and drag forces acting upon the swimmer will be discussed using literature to compare and contrast theories.

The evolution of dry land training, strength training, and resistance training in the water during the last five decades has pushed the sport to new heights. Designing programs to increase power, strength, and agility are becoming vital to the success of the collegiate swimmer. Although the literature supports the use of power training in the water,[1,2] studies have criticized elements of this type of training and recommend using resistance training sparingly, sighting undesirable changes in stroke length and stroke rate.[12]

Male and female collegiate swimmers compete in four different strokes: Freestyle, Backstroke, Breastroke and Butterfly. Freestyle is the most common stroke, with races at the 50-yard, 100-yard, 200-yard, 500-yard, 1000-yard and 1650-yard distances. For the other three strokes, only the 100-yard and 200-yard are represented as individual events. There are two individual races in which the swimmer completes all four strokes in one race called the Individual Medley. The Individual Medley or IM is represented at the 200-yard and 400-yard distances in college swimming. Sprinters most commonly swim the 50-yard and 100-yard distances with the occasional 200-yard swim. Middle distance swimmers primarily swim the 100-yard and 200-yard distances with the occasional 400 IM or 500 Free. Distance swimmers primarily swim events of 200-yards or more. Although power is essential to the success of all events, training for the sprint events (50-yard and 100-yard) concentrates more on developing power.

Generating power in swimming has many factors. The initial force that propels the swimmer is the start. For the start of a swimming race, power is used to drive the swimmer off of the block. Once the swimmer enters the water, underwater dolphin kicks propel the athlete toward the surface of the water. During the dive, the athlete streamlines in order to transfer as much of the power generated on the block into the water.

The streamline is formed when the swimmer stretches the arms above his or her head and crosses the arms. The hands are locked above the head in line with the spine. Streamlining allows the swimmer to reduce drag and maintain the power generated off of the block while entering the water. Over time, the streamline has evolved drastically. As swimmer's flexibility has increased, so has their ability to reduce drag in the water. Once the swimmer reaches the surface, he or she transitions to swimming on top of the water by performing a breakout. After the swimmer breaks the surface of the water via a breakout, the power of the individual determines the number of strokes and time it takes to perform each stroke. In short course swimming, the swimmer swims 25-yards until he or she has an opportunity to perform a turn and push off the wall. Pushing off of the wall increases speed drastically compared to swimming and is considered a major component of short course swimming success. The start, swimming stroke and the turn are all components of the race that depend on the power of the individual. Head coaches and strength coaches have recognized this fact and are increasing the importance in weight room training in order to increase power in the water. In the last three decades, weight training has moved toward Olympic lifting, making the swimmer more explosive. In-water training has evolved to include resistance training to improve power and thus performance in the start, turn and stroke of the swimmer.

Power Training Apparatus

The two most common apparatus used to perform resistance training are the power tower and power racks. Power Towers consist of two large 20 gallon buckets attached to a pulley system. During training, swimmers will attach themselves to the pulley system with a belt to swim against resistance. The pulley system allows the swimmers to swim the entire length of the pool in Short Course Yards (25-yard). Power racks attach to the swimmer in a similar way, except the belt attaches to a series of weight plates, instead of the bucket system. The swimmer can easily adjust the weight by adjusting a pin. The power rack does not stretch across the entire pool. The pulley system is best utilized when the swimmer pushes off of the wall parallel to the power rack in order to move the resistance immediately. Swimmers perform a short streamline followed by underwater butterfly kicks before they break the surface and begin swimming freestyle.

Energy Training Zones

Power output is a major determinant of swimming performance, and is determined by the swimmer's ability to utilize aerobic and anaerobic metabolism to generate energy. Sprint events mostly utilize anaerobic metabolism. Aerobic metabolism is needed to complete repeat performances during training. The ability to use lactate and clear waste products from the muscles and blood make both anaerobic and aerobic systems important to the elite swimmer. When training an elite swimmer, understanding the muscle fiber types and energy system used to perform specific events is key. Energy is required to swim from one end of the pool to the other. The contraction of muscles during swimming is supplied by the breakdown of adenosine triphosphate (ATP). Creatine phosphate (CP) and glycogen are two chemicals that are stored in the muscles that replenish ATP.[17] During a race, ATP and CP, known as the high-energy phosphates, provide most of the energy at the start of the race. After creatine stores are depleted, anaerobic metabolism, or the breakdown of glycogen into lactic acid, acts to replace ATP.[17] The most efficient way to replace ATP is aerobic metabolism, in which oxygen is consumed. At faster speeds, anaerobic metabolism rapidly produces ATP at a high-energy cost. Hinzpeter et al. (2013) reported that after an intense swim, swimmers who completed an active warm down reduced lactate levels 5.93 mmol·L(-1)) or 68%. The control group that did not complete an active warm down only saw a decrease of 1.63 mmol·L(-1)) or 20%, suggesting that both anaerobic and aerobic systems are important when training at short distances and high intensity. The anaerobic system is utilized in sprint events in which the rate of blood lactate increases faster than the body can oxidize the lactate formed and acid is removed. This creates fatigue and metabolites that impair swimming function. Training should target the aerobic and anaerobic systems so that both systems work together maximize performance.[7]

Ernie Maglishco, one of the leading sports scientists in swimming described the different training zones and their corresponding muscle fibers. The training zones are associated with the blood lactate values at a given speed. Recent research has proven that lactate itself is used by the muscle as fuel, therefore the blood lactate values are tracked in order to estimate the level of harmful metabolites associated with anaerobic respiration.[8] Maglishco describes 3 different velocities and six training zones that are associated with the lactate curve. Aerobic threshold, the anaerobic threshold, and VO2max are the three velocities that separate the training zones on the lactate curve.[6]

Maglischo details 6 training zones separated by velocity: the recovery zone, aerobic training zone, anaerobic threshold training zone, combined aerobic/anaerobic training zone, VO2 max training zone and the anaerobic training zone.[6] The recovery zone is used in between intense repetitions during training to allow the blood lactate and waste products to clear the muscle and blood and the swimmers heart rate return to lower values. Immediately above the recovery zone is aerobic threshold, the minimum velocity where training effects are produced. The first endurance-training zone is titled En-1 and is used to train the aerobic processes of slow twitch fibers. En-1, or the slow twitch training zone's upper limit is defined by anaerobic threshold. Anaerobic threshold is defined as the point at which lactate production and lactate clearance are in equilibrium. Above the anaerobic threshold, lactate clearance is unable to keep up with lactate production and is characterized by pain and fatigue. En-2, which resides above the anaerobic threshold is the zone at which the metabolic processes of fast twitch a fibers are trained. The upper limit of En-2 is Vo2 max, the maximum volume of oxygen that can be consumed while breathing air at sea level. En-3 resides above Vo2 max and is used to train the aerobic metabolic processes of fast twitch x fibers. EN-2 and EN-3 zones are primarily used to improve aerobic metabolic function of fast twitch fibers due to the higher speeds required to reach these zones. However, sprint oriented athletes must train at faster speeds to recruit fast twitch fibers, even when developing their aerobic capacity. While training in En-1 & En-2, there are improvements to fast twitch lactate removal and buffering of waste products that occur. Sprint training is unique due to its purpose, which is to increase stroke power and energy release from ATP and CP.[6] In sprint training, the goal is to move through the water as fast as possible. Maglishco recommends that enough rest be taken between reps so that metabolite accumulations do not impede the swimmers speed. For the last two decades, swimming at the elite level has moved to shorter more intense training. Coaches' understanding of muscle fiber types and the way they change with training has driven much of this change. The shift to shorter more intense training is coupled with the innovation of power training with resistance in the water. Programs at the elite level are finding success in understanding the individual nature of each athlete.

In Swimming, key differences in the physiology of each athlete influence their response to different methods of training. Sex and event type are two of the most important aspects to consider when creating an individualized training program. Muscle thickness, fascicle length, and ability to buffer metabolic acids are physiological differences between athletes that influence swimming performance. In The Development and Prediction of Athletic Performance in Freestyle Swimming, a group of Polish scientists found evidence that in the sprint events (50-yard and 100-yard) women and men's results exhibit the largest gap in performance. Male and female results differed by 11.47 % in the 50-yard Free with the average time of male and female finalists were 21.3 and 24.6 seconds respectively. Male finalists swam an average of 47.2 seconds and female finalists swam an average of 53.1 seconds, a difference of 11.13 %. Male and female finalists swam an average time of 1:42.96 seconds and 1:54.82 seconds respectively in the 200-meter free, a difference of 10.33 %. The 400-meter distance exhibited an 8.78 % difference. As the distance increases, women's and men's performance are more similar.[9] Stanula et al. (2012) analyzed the results of the 50-meter, 100-meter, 200-meter and 400-meter freestyle final for every Olympics from 1896 and 2008. The 50-meter distance is the shortest and the newest freestyle event of the Olympic games, debuting in Seoul 1988. During the twenty years analyzed, the female finalists improved by 1.55 seconds or 6.0 % and the males improved Kolmogorov 1.28 seconds or 5.5 %. The analysis of the 100-meter free spans the Olympics from the year 1958 to 2008. Male swimmers improved 10.84 s or 18.6% and female swimmers improved 13.58 seconds or 20.1% during that period. The 200 freestyle has improved 17.38 seconds or 13.1 % for women and 14.72 seconds or 12.3 % for men between 1968 and 2008.[9] Women's improvement is accelerating faster, especially in longer events, than men's and could be attributed to the well-developed aerobic system of women.[9] Three German scientists Benjamin Holfelder, Niklas Brown and Dieter Bubeck examined the influence of sex, stroke and distance on the Individual Anaerobic Threshold (IAT). These scientists looked at Data from 172 females and 228 males in order to find correlations in sex, stroke and distance in the lactate profiles of the swimmers. Lower lactate concentrations of women support the idea of a more developed aerobic metabolism in women compared to men.[2] Men produced more lactate during the IAT test for every event 200-meters and under. As the distance increased, the values grew closer, with the women producing more in the 400 Free than the men. Men produced 6.19 ± 0.99 mmol·L(-1)) and the women produced 5.76 ± 1.01 mmol·L(-1)) during the 100 free. Men produced 5.70 ± 0.95 mmol·L(-1)) and the women produced 5.33 ± 1.04 mmol·L(-1)) during the 200 free. Men produced 5.19 ± 1.19 mmol·L(-1)) and the women produced 5.21 ± 1.16 mmol·L(-1)) during the 400 free.[2] The German's results suggest that because women have higher fat content, buoyancy is increased in the water. This could aid in the longer swimming events and partially explain the lower percentage difference between male and female distance performances, supporting the Stanula et al 2012 claim that sprint events reveal the largest gap in performance between men and women.[9]

The most successful collegiate teams divide up swimmers into specified groups. These high-powered teams in the "Power 5" conferences (SEC, ACC, Big 12, PAC 12, and Big 10) have larger staffs and more resources available to split into smaller groups and train athletes more individually. On these teams, on any given day, three groups are practicing simultaneously. Sprint, Middle Distance, and Distance swimmers are divided into groups with the intent of focusing on a certain energy system or event. In the sprints (50-yard and 100-yard swims), anaerobic glycolysis is more heavily utilized than in the distance events. The large demand for muscular power in the sprint events creates higher lactate concentrations.[9] Holfelder et al.

(2013) analyzed lactate concentrations during freestyle races and found Men produced 6.19 ± 0.99 mmol·L(-1)) and the women produced 5.76 ± 1.01 mmol·L(-1)) during the 100 free.

Middle distance focuses on the 100 and 200-yard distances. Swimmers in this group represent a wide variety of the genetic spectrum. Some athletes are more distance oriented and aerobically gifted that "train down" to race the 100 and others are more fast twitch oriented or speed driven that "train up" to the 200. Designing training to accommodate the wide variety of the middle distance group requires an understanding of the physiological differences between swimmers across different events, sex and ability levels.

Kolmogorov et al (1992) designed an experiment to compare sprinting performance and muscle fascicle length in 23 young male swimmers. The participants were divided into two groups based on their best 25-meter sprint time. The faster group, S1 consisted of 11 athletes ranging from 14.6-15.7 seconds for the 25-meter sprint. S2, the slower group, consisted of 12 athletes ranging from 15.8 – 17.0 seconds.[4] The two groups did not exhibit a significant difference in standing height, body mass, arm length, thigh length or leg length. The two groups did show significant differences in muscle thickness and fascicle length. The study sighted various other studies supporting the theory that fascicle length is an important factor in maximal shortening velocity.[4] Longer fascicle length will result in greater maximal shortening velocity. Faster velocity results in greater power and sprinting performance as long as the force is maintained. Kumagai et al. (2000) tested thirty-seven male sprinters in the 100-meter distance. Significant negative correlations between absolute fascicle length and 100-meter sprint time in the vastus lateralis (r=-0.44 P<0.01), and gastrocnemius lateralis (r=0.40,

$P<0.05$).[19] The study supports the theory that longer muscle fascicle length is a positive influence on power.

Taper is a period of rest before a major competition. Swim programs lessen the intensity and duration of training to allow the body to heal and perform at optimum capacity. Very little research has been conducted on swimmers during taper. Men require more rest than women due to the fact that men have a higher percentage of muscle mass and produce more lactate.[5] Coaches rely on instinct and experience when designing taper for a given athlete. There is a limited amount of studies that have been conducted to give some insight into the process of tapering.

There has been a large amount of debate over the years on the role of lactate during training. Once thought to be a waste product, now lactate is seen as a valuable energy source. Residual levels of lactate in the blood were used as markers of fatigue during intense bouts of training. It is extremely important to understand the role of lactate in repeated intense bouts in order to maximize performance at a swimming competition & during training.[8] Lactate produced during a maximal effort requires time to return to a base level. There is much debate about the factors that affect the lactate returning to baseline. More muscular individuals produce a higher volume of harmful waste products associated with anaerobic respiration. The process in which lactate and the harmful waste products such as ammonia and hydroxide are cleared from the blood is called lactate clearance. William et al. (1989) tested participants that completed three maximal swims and recovered at different intensities. The men's lactate levels were 8.8 mmol·L(-1)) vs 5.5 mmol·L(-1)) for the women after the first swim. The men's lactate levels were 9.3 mmol·L(-1)) L vs 6.0 mmol·L(-1)) for the women after the final swim. Men produce a higher volume of harmful waste products than women. William et al. (1989) concluded that a 65% recovery swim reduced blood lactate the most in comparison to the amount created, 22 % for men and 16 % for women.[11] Studies in the past have concluded that swimming in between intense bouts of exercise will aid in facilitating lactate clearance. Active recovery is more beneficial than passive recovery or rest when attempting to repeat intense bouts of exercise.[8]

The understanding of physiological differences between athletes has driven change in swimming. Sprinters especially are swimming less yards than ever in order to develop the fast twitch 2ax fibers and protect the muscles from shifting these fibers to their slower 2ab counterparts. The most successful programs have increased the intensity to more race pace training across all distances. Muscle fascicle length, ability to buffer lactate waste products, muscle fiber type, and muscle thickness are physiological differences that should be taken into account when developing a competitive training plan.

Understanding the history of in-water power training is important when attempting to design a uniform power test. Different study designs have strengths and weaknesses that will be considered when comparing and contrasting methods of power testing. Scientists have worked with different apparatus to measure the effects of resistance training in the water. The MAD system of fixed push-off points, a motorized wheel providing assistance or resistance, a stretch cord attached to the side of the pool are examples of devices used to test in water power. The study design, number of participants, duration of the bout, and rest between maximal bouts are elements that will be considered in the following section.

In 1990 Toussaint described a system to measure active drag (MAD) that used fixed push-off points (POP) in the water. The participants in the study either performed sprints once a week on the POP system, or normal sprints. Each group consisted of eleven swimmers. The POP had limitations when mimicking the natural swimming motion. Swimmers in the experiment had to hit the fixed platforms in order to get a proper force reading, which may not be the same place a swimmer naturally placed the hand during a sprint.[1]

A group of Australian Scientists conducted an experiment on four female junior athletes 17 ± 2.3 years in which they would swim normal, resisted, and assisted. For both the assisted and resisted trials, a motorized reel with a cable attached to the swimmers via Velcro was used to apply force to the swimmer.[12] Normal sprints were performed with no resistance or assistance. The purpose of the experiment was to investigate the effects of positive and negative force on stroke length, stroke rate, maximum hand depth, hand velocity, body roll off the shoulders and hips, and average forward velocity. The swimmers completed three 50-meter sprints randomized by condition (assisted, resisted, and normal). The swimmers had a familiarization session in which they swam practice trials with assistance and resistance. This method of swimming with resistance via a motorized wheel gives the athlete more freedom to perform a natural swimming motion compared to the above MAD system. The scientist however did discuss a negative influence on stroke length and technique with this method that the MAD system could account for. For more reliable conclusions, the experiment could be performed with more than four individuals.

In a similar experiment, nineteen male and twenty-six female sprinters were recruited to complete the three-week program.[14] Only 16 men and 21 women completed the entire protocol due to injury and dropout. The swimmers were randomly divided into three groups: resisted sprint, assisted sprint, and control. The over strength or resisted sprint group swam 6 all out 30 second front crawl sprints with 30 seconds of recovery in between. The over speed group swam twelve 25-meter sprints. The control group swam six 50-meter all out front crawl sprints without the elastic tube. The over speed group was pulled toward the point of arrival by a tethered elastic tube.[14] The over strength group had the same tube with the force pointing in the other direction, loading more force on the swimmer as he or she swam. Both of these experiments used a randomized design to select when the subject would perform assisted sprints, resisted sprints and sprints with no resistance or assistance. Randomizing the design in the latter experiment would strengthen the reliability of the results and help to eliminate a learning effect. Muscle strength was improved the most in the over strength group. There was no significant difference between the control and over speed groups. For swimming performance, the over strength group saw improvement over all three weeks of the program. The over speed group showed improvement between the second and third weeks only. The control group showed no significant improvement. Over the testing period the over strength group improved 2 %, the over speed group 0.8 % and the control 0.3 % in their 100-meter time.[14]

When designing a power test, the type of recovery between repetitions should be considered in order to maximize performance. A group of scientists at the University of Chile hypothesized that regeneration exercises in swimming increase the clearance of blood lactate and therefore improve athletic performance within a single day of competition.[15] The authors designed a crossover study in which swimmers went through three stages. The pre-test stage consisted of 20 minutes of stretching (warm-up) and a times 100 freestyle at maximum effort, followed by a five-minute rest. The second stage, the exercise test consisted of 3 sets of 4 x 200-meters with increasing intensity[15]. The swimmer was instructed to swim at 65-70% of max effort on the first round, 80% on the second round and 100 percent on the third round. Between each set, lactatemia was recorded using an Accutrend lactate analyzer. The final stage, the dichotomic stage, consisted of one group of randomly selected swimmers performing regeneration exercises, and the other group resting.[15] After the last stage, another 100-meter sprint was performed and the results analyzed. The lactate values for both groups increased 78 % or 4.6 mmol·L(-1)). The active recovery group decreased lactate levels 68 % or an average decrease of 5.93 mmol·L(-1)) while the passive group decreased 20 % or 1.63 mmol·L(-1)). The crossover design allowed the scientists to determine if the regeneration exercises affected the performance and the levels of lactate in the swimmers. The scientists collected lactate data in between every stage.

McMaster & Stoddard collaborated with one of the most successful swim programs in U.S. history in 1989 to investigate active recovery at different intensities. Six senior national swimmers (3 men and 3 women) performed 3 challenge swims of 200-yards. Each challenge swim was followed by active recovery. The speed of the recovery swim was a percentage of the speed of the challenge swim. The first recovery swim was set at 65 % of the challenge swim.[11]

The second recovery swim was performed at 55 % and the third at 75 %. After the challenge swim, a 2-minute blood lactate sample was recorded before the swimmer recovered. Each of the active recovery experiments take a different approach on the performance of active recovery swims between repetitions.

Both the Chilean experiment & McMaster & Stoddard collected heart rates, lactate levels and measured performance at each stage to determine the effect of the recovery swims. For both experiments, the swimmers performed bouts of 200-yards. This distance is a good balance to perform at a high speed for a prolonged distance in order to produce the maximum amount of lactate. The Chilean protocol consisted of active recovery in between each of the three stages while McMaster and Stoddard had one stage of recovery. The fact that some swimmers were selected to perform no recovery gave valuable insight into the effect of the recovery while the Chilean experiment helped to hone in on the effects of recovery at different intensities. The experimental design of the Chilean study was weak due to the lack of variation in the recovery swims. In order to test different intensities more effectively, a randomized design should be adapted. To make the results more accurate, some swimmers would need to complete the 75 % recovery swim 1st and 2nd as well as the 55 %. Repeated bouts of intense exercise could delay the lactate levels returning to base. The fact that the 65 % recovery swim was completed by first by all of the subjects is a weakness in the experimental design.

Results of power training in the water

To justify the need for a uniform power test, evidence is needed to support the theory that power training in the water increases performance. Although the literature supports the use of power training, scientists have discussed the limitations past experiments with regards to the effect of swimming technique. The training group from Toussaint's 1990 study that performed on the MAD system increased force from 91 to 94 N (3.3 %), velocity from 1.71 to 1.81 $m \cdot s^{-1}$ (3.4 %) and power from 160 to 170 W (7 %).[1] In a French experiment, swimmers performed sprints with resistance (over strength), with assistance (over speed) and with no resistance or assistance (control). Muscle strength was improved the most in the over strength group. There was no significant difference between the control and over speed groups. For swimming performance, the over strength group saw improvement over all three weeks of the program. The over speed group showed improvement between the second and third weeks only. The control group showed no significant improvement. Over the testing period the over strength group improved 2 %, the over speed group 0.8 % and the control 0.3 % in their 100-meter time.[14] In conclusion, this study supports the literature that training with resistance is more efficient than assistance when training for the 100-meter freestyle.[1,14]

Technique

The literature aligns in stating that although swimming with resistance increased strength and performance, the undesirable side effects of resistance training should be considered when designing a training program for elite swimmers. In the Australian experiment, which focused on the technique of four female junior elite swimmers performing resisted, assisted, and free sprints concluded that there was a significant difference among stroke length, stroke rate, hand depth, and average forward velocity between the conditions.[12]

There were no significant differences between hand velocity, shoulder angle, and hip angle. The resisted trials caused a decrease in stroke length, stroke rate and hand depth. Undesirable changes in stroke length and stroke rate occur when swimming against resistance. The study however, did not look into the effects on performance over a period of time. Maglischo and Sharp reported similar results in 1985. Maglischo determined that technique is negatively affected with both resisted and assisted training.[12] Stroke length, as well as the stroke rate decreased due to the increased resistance affecting the swimmers. They also concluded swimming against resistance created shorter and slower stroking when analyzing four male and two female age group swimmers swimming butterfly.[12] These outcomes suggest that resistance training should be a limited part of an elite training program. Swimmers need repetitions that mimic the conditions in which they will race at the end of the year.

Active vs Passive Recovery

McMaster & Stoddard collaborated with one of the most successful swim programs in U.S. history in 1989 to investigate active recovery at different intensities. Active recovery is more effective in returning lactate to basal levels than passive recovery. The results concluded that the 65 % recovery swim, compared to a 55 % and 75 % swim, reduced blood lactate the most in comparison to the amount created, 22 % for men and 16 % for women.[11] The recovery period should immediately follow the race and is performed in nearly every situation in high level competitive swimming.

During the exercise phase of a study at the University of Chile clinical hospital, the athletes lactate levels increased with increasing intensity. Both groups increased 4.6 mmol·L(-

1)). In the recovery phase the active recovery group saw an average decrease of 5.93 mmol·L(-1)), while the passive group decreased a mere 1.63 mmol·L(-1)). This study supported McMaster & Stoddard's findings that the supports the literature in stating that active recovery is a necessary tool when lowering lactate levels during competition.[11]

Thesis Objectives

The sport of swimming would benefit from a way to test power in the water that is relatable to the results of the Wingate power test. The objectives of the power test are to:

1) Standardize the in-water test as a valid way to test power by relating it to the Wingate test. 2) Discover the resistance at which each participant should pull to maximize power for a 25-yard sprint. 3) Compare and contrast data of men and women. 4) Compare and contrast data from swimmers of the three training groups (Sprint, Middle Distance, and Distance). 5) Correlate land power via the vertical jump test to in-water power. The literature supports the use of strength training as a means of increasing power in the water and performance at a championship competition. Sex, event type and physiology of the individual athlete should be considered when designing water based power training. For this test, active recovery between repetitions will benefit future performances and recovery of lactate levels. Although technique can be negatively affected by swimming with resistance, resistance training is an integral part of collegiate swim training.

Hypotheses

1) Sprinters will have a higher average power output and decelerate faster than middle distance and distance swimmers.
2) Sprinters will have a higher vertical jump than middle distance and distance swimmers.
3) Men will have higher average power and power per stroke than women.
4) Women’s power curves will decelerate slower than men’s
5) The participants rank for fatigue index on the Wingate test and deceleration during the in water test will correlate.

CHAPTER 2: METHODS

Participants

Men and women from the LSU swim team between the ages of 18.0 and 30.0 years (mean 21.4 years). Ten subjects completed the protocol with one dropping out after the in-water test, before the land performance profile. The five women recruited were two sprinters, two middle distance swimmers, and one distance swimmer. The five men recruited were four middle distance swimmers and one distance swimmer. The participant that dropped out was a male middle distance swimmer.

Study Design

Participants completed two days of testing, in-water and land-based performance testing. The participants performed the in-water test on the first day of testing. The second day of testing consisted of a land-based performance profile made up of the Wingate Test for Anaerobic Power and a vertical jump test. The participant's height and weight was recorded at the second visit.

In-water test

For the in-water test, each participant was given a 15 minute warm-up period to prepare for the maximal test. The in-water test was a series of weighted 25-yard swims. Each participant hooked into a harness that was attached to a pulley system and to a bucket. Men performed the first trial with 40 lbs in the bucket; women performed the first trial with 20 lbs in the bucket. After each successful 25-yard swim, the participants performed 3 minutes of active recovery. Men increased the weight 20 lbs after each successful trial. Women increased the weight 15 lbs after each successful trial. The test was completed every 3 minutes until the swimmer was unable to reach the other side of the pool. Failure to reach the full 25-yards resulted in 3 minutes of active cool-down and the choice of attempting a weight between the last successful trial and the previous failure. If the swimmer chose to complete another trial, it was their last regardless of the outcome.

Performance Profile: Wingate Test

The participants performed the Wingate on the Velotron cycle ergometer (Racermate, Inc, Seattle, WA, USA). Prior to performing the Wingate, the participant cycled at a low RPM and load (25Watts) for 5 minutes (Example Figure 1a). The prescribed force used was a torque factor of 7.5 percent of body weight. After the warm-up procedures, the participant performed a 30 second all out sprint to determine power output. The tester initiated the test with a verbal command “Go!” The participant began pedaling as fast as possible for the 30-second period. At each 5-second interval the tester indicated the time. At the 30-second mark, the tester stopped the test with the verbal command “Stop!” Peak and mean power were recorded for the duration of the test. Following the test, the participant performed a 3-minute active cool-down.

Performance Profile: Vertical Jump Test, Height & Weight

Each participant performed a static vertical jump test using the Vertec Vertical Jump Tester (Knoxville, TN). The participant had two trials to jump as high as possible from a standing position (Example Figure 1b). The greater of the two values were recorded as maximum jump height. The participant was instructed to bend the knees and use his or her arms for propulsion. The vertical jump data will be used as a representation of land power. The participant’s height and weight were recorded.

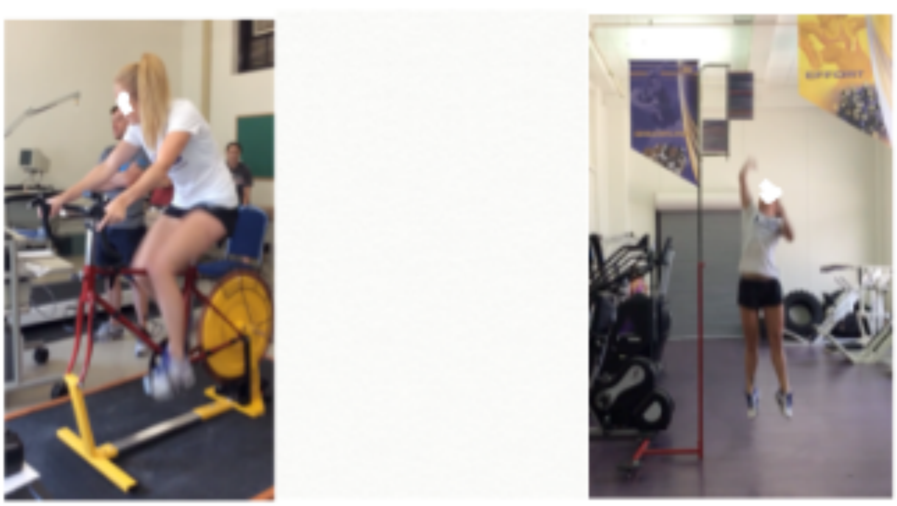

Fig 1a. Fig 1b.

Figure 1a. Participant on Velotron Bike prior to Wingate Test
1b. Participant performing static vertical jump with Vertec jump tester

Data Collection

In-water Test

Data was collected by a GoPro Session camera (Woodman Labs, San Mateo, CA) attached to the side of the Power Tower (Total Performance, Mansfield, Oh); bucket). The GoPro camera recorded a tape measure to track the progress of the bucket's travel. The GoPro video footage kept an accurate measure of time. The number of inches traveled over time was collected twice per second. Video footage was analyzed via Final Cut Pro (Apple, Cupertino, Ca). A digital line was inserted into the video to mark the position on the tape measure (DeWalt, Milwaukee, Wi). During the test, the participant will be recorded on an Ipad (Apple, Cupertino, Ca) to collect the stroke count at each weight.

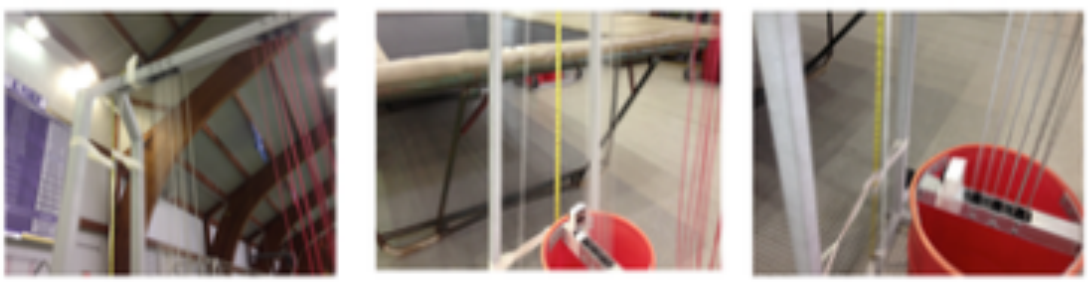

Fig 2a. Fig 2b. Fig 2c.

Figure 2a. Tape measure attached to top of power tower
2b, 2c. GoPro Camera attached to power tower bucket

The Total Work (J), Average Power, Speed (m/s), Average Deceleration (m/s^2), number of strokes, and work per stroke ($J \cdot stroke^{-1} \cdot kg^{-1}$) were collected for each 25-yard swim (see equations below).

Total Work = weight in Kg * d (distance traveled on tape measure)

Avg Power (W) = Total Work (J)/time (s)

Speed = 25 yards (22.86m)/time (s)

Work per stroke (J) = total work (J)/number of strokes (n)

Average Deceleration = Total Change in speed per second/(s)

Relative Power for In-Water test (W/kg) = Avg power (W)/body weight (kg)

Work per stroke ($J \cdot stroke^{-1} \cdot kg^{-1}$) = Avg power (W)/body weight (kg)/# of strokes

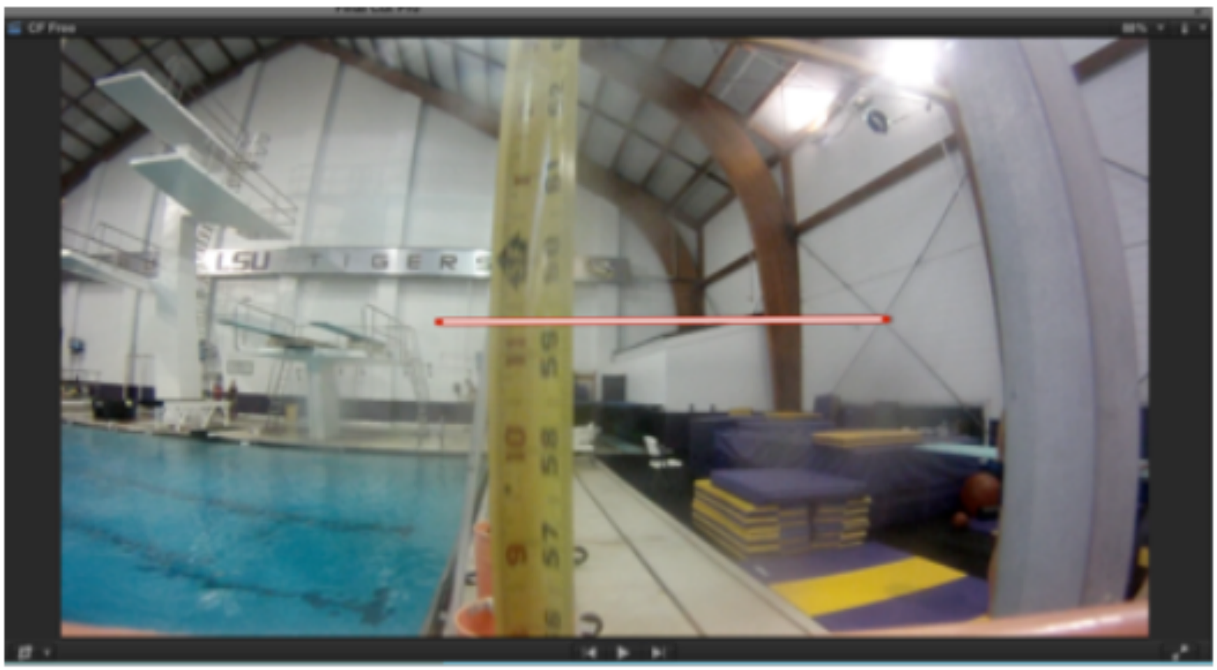

Figure 3. Example of digital red line on Final Cut Pro movie sofware

Wingate

The Velotron bike reported values for Mean Watts, Peak Watts, Minimum Watts, Mean RPM, Peak RPM, Min RPM, Anaerobic Capacity (W/kg), Anaerobic Power (W/kg), Fatigue index (W/sec), and Total Work (J). Participants will be ranked 1st to 5th for each of the variables.

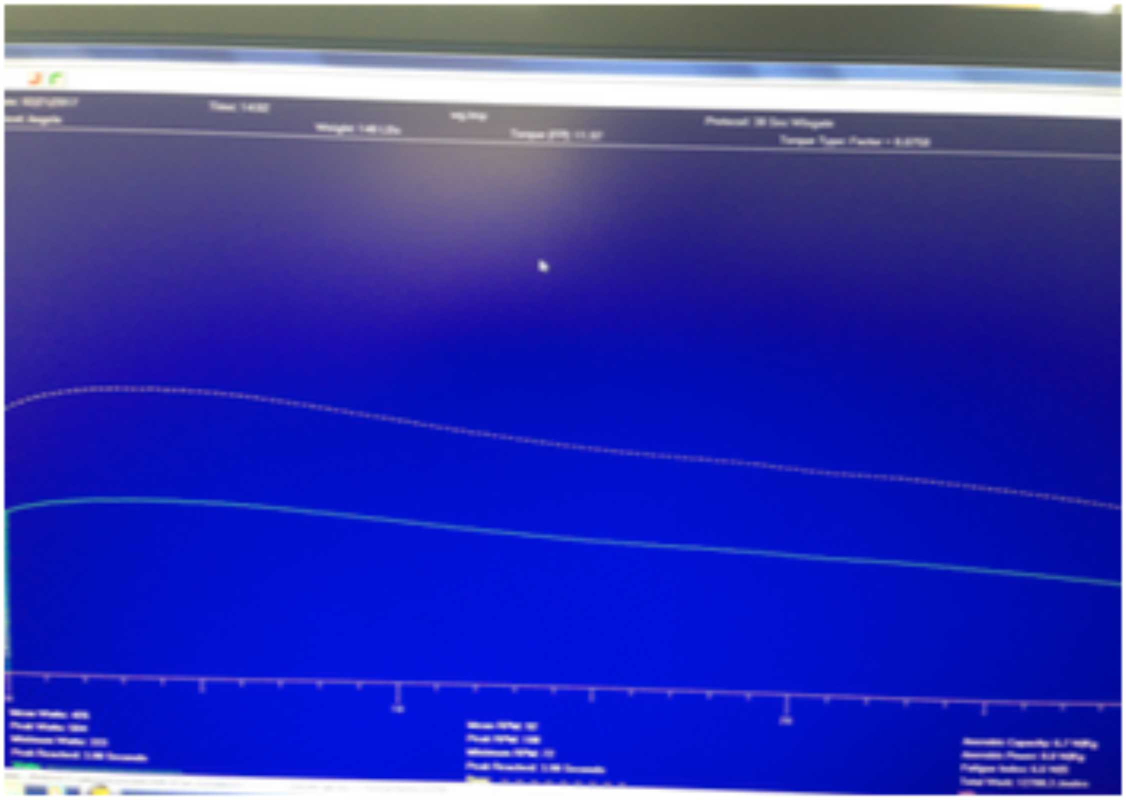

Figure 4. Velotron Wingate Report

Table 1. In-Water Data Report

Data Point	Time	Position on TM (in)	Dis from last point	Distance from LP (m)	Work (J)	Accel	Total Work (J)of Bucket	Power = Watts= J/s
0		30	0	0	0			
1	0.5	33.35	3.35	0.08509	13.240004		13.240004	26.480008
2	1	35.5	2.15	0.05461	8.497316	-0.03048	21.73732	21.73732
3	1.5	37.55	2.05	0.05207	8.102092	-0.00254	29.839412	19.89294133
4	2	39.5	1.95	0.04953	7.706868	-0.00254	37.54628	18.77314
5	2.5	41.4	1.9	0.04826	7.509256	-0.00127	45.055536	18.0222144
6	3	43.3	1.9	0.04826	7.509256	0	52.564792	17.52159733
7	3.5	45.2	1.9	0.04826	7.509256	1.8041E-16	60.074048	17.16401371
8	4	47.1	1.9	0.04826	7.509256	-1.804E-16	67.583304	16.895826
9	4.5	48.65	1.55	0.03937	6.125972	-0.00889	73.709276	16.37983911
10	5	50.55	1.9	0.04826	7.509256	0.00889	81.218532	16.2437064
11	5.5	52.3	1.75	0.04445	6.91642	-0.00381	88.134952	16.02453673
12	6	54.2	1.9	0.04826	7.509256	0.00381	95.644208	15.94070133
13	6.5	55.9	1.7	0.04318	6.718808	-0.00508	102.363016	15.74815631
14	7	57.45	1.55	0.03937	6.125972	-0.00381	108.488988	15.49842686
15	7.5	59.2	1.75	0.04445	6.91642	0.00508	115.405408	15.38738773
16	8	61	1.8	0.04572	7.114032	0.00127	122.51944	15.31493
17	8.5	62.7	1.7	0.04318	6.718808	-0.00254	129.238248	15.20449976
18	9	64.35	1.65	0.04191	6.521196	-0.00127	135.759444	15.08438267
19	9.5	65.9	1.55	0.03937	6.125972	-0.00254	141.885416	14.93530695
20	10	67.65	1.75	0.04445	6.91642	0.00508	148.801836	14.8801836
21	10.5	69.15	1.5	0.0381	5.92836	-0.00635	154.730196	14.73620914
22	11	70.85	1.7	0.04318	6.718808	0.00508	161.449004	14.67718218
23	11.5	72.35	1.5	0.0381	5.92836	-0.00508	167.377364	14.55455339
24	12	74	1.65	0.04191	6.521196	0.00381	173.89856	14.49154667
25	12.5	75.65	1.65	0.04191	6.521196	0	180.419756	14.43358048
26	13	77.1	1.45	0.03683	5.730748	-0.00508	186.150504	14.31926954
27	13.5	78.7	1.6	0.04064	6.323584	0.00381	192.474088	14.25733985
28	14	80.4	1.7	0.04318	6.718808	0.00254	199.192896	14.228064
29	14.5	81.8	1.4	0.03556	5.533136	-0.00762	204.726032	14.11903669
30	15	83.1	1.3	0.03302	5.137912	-0.00254	209.863944	13.9909296
31	15.5	84.75	1.65	0.04191	6.521196	0.00889	216.38514	13.96033161
32	16	86.1	1.35	0.03429	5.335524	-0.00762	221.720664	13.8575415
33	16.5	87.75	1.65	0.04191	6.521196	0.00762	228.24186	13.83284
34	17	88.85	1.1	0.02794	4.347464	-0.01397	232.589324	13.68172494
35	17.5	90.25	1.4	0.03556	5.533136	0.00762	238.12246	13.60699771
36	18	91.65	1.4	0.03556	5.533136	0	243.655596	13.536422
37	18.5	93	1.35	0.03429	5.335524	-0.00127	248.99112	13.45897946
38	19	94.7	1.7	0.04318	6.718808	0.00889	255.709928	13.45841726
39	19.5	95.9	1.2	0.03048	4.742688	-0.0127	260.452616	13.35654441
40	20	96.9	1	0.0254	3.95224	-0.00508	264.404856	13.2202428
41	20.33	97.15	0.25	0.00635	0.98806	-0.01905	265.392916	13.05425066

Table 2. Participants Individual Data Report

FS4-1	Time (s)	Total Work (N)	Avg Work (N-m/s)	Speed m/s	Avg Decel (m/.5s)	# of Strokes	N-m/Stroke	Slope	y intercept
20 lbs	19.71	153.09	7.76	1.14	-0.0774	25	6.1236		
35 lbs	20.33	265.4	13.05	1.124	-0.00225	27	9.83		
50 lbs	22	379.61	17.26	1.04	-0.0024	33	11.5		
65 lbs ***	26.7	502.385	18.8	0.86	-0.00147	42	11.96	-0.3367	27.706
80 lbs	14.1	280.57	19.9	1.03	-0.002522	23	12.199		
Wingate Test									
	Mean Watts	Peak Watts	Min Watts	Watts Peak Reached	Mean RPM	Peak RPM	Min RPM	RPM Peak Reached	
Vert Jump	426	584	333	3.9	92	100	82	1.7	
23.5 in									
	Anaerobic Capacity		Anaerobic Power		Fatigue Index		Total Work	Ht (cm)	Wt (kg)
Sprinter	7.4 W/kg		8.6 w/kg		8.2 w/s		20187.5 J	168.2	63.3

Data Analyses

In-Water Test

Anaerobic power was compared between sprinters, middle distance swimmers and distance swimmers using a 1-way Analysis of Variance (ANOVA). The trial in which each participant had the highest average power was selected to analyze. Data were analyzed for absolute (W) and relative (W/kg body weight) power (Example table 1).

Wingate Test

The Total Work (J), Fatigue index (W/s), Anaerobic Power (W/kg), and Mean Watts (W) were calculated by the Velotron software program (Example Figure 4). The participant's data was compared between sex and swim distance. The average watts on the Velotron were compared to the average watts on the in-water test.

Vertical Jump Test

The relative power was calculated for each participant using the Lewis Equation:

$$\text{Average Power (Watts)} = \sqrt{4.9 \times \text{body mass (kg)}} \times \sqrt{\text{jump-reach score (m)}} \times 9.81$$

The relative power of the vertical jump test was compared to peak power and relative power for the in-water test. The participants were weighted in the lab immediately before the vertical jump on the second day of the test.

Slope vs Fatigue Index

The slope of the power curve indicated the rate of power decay. The data for the line of best fit for the rate of decay started after the initial push-off (figure 5). The rate of decay of sprinters, middle distance swimmers and distance swimmers were compared to the fatigue index of the Wingate test. The rate of decay for the Wingate test and the slope of the power curve for the in-water test were analyzed to reflect differences between men and women.

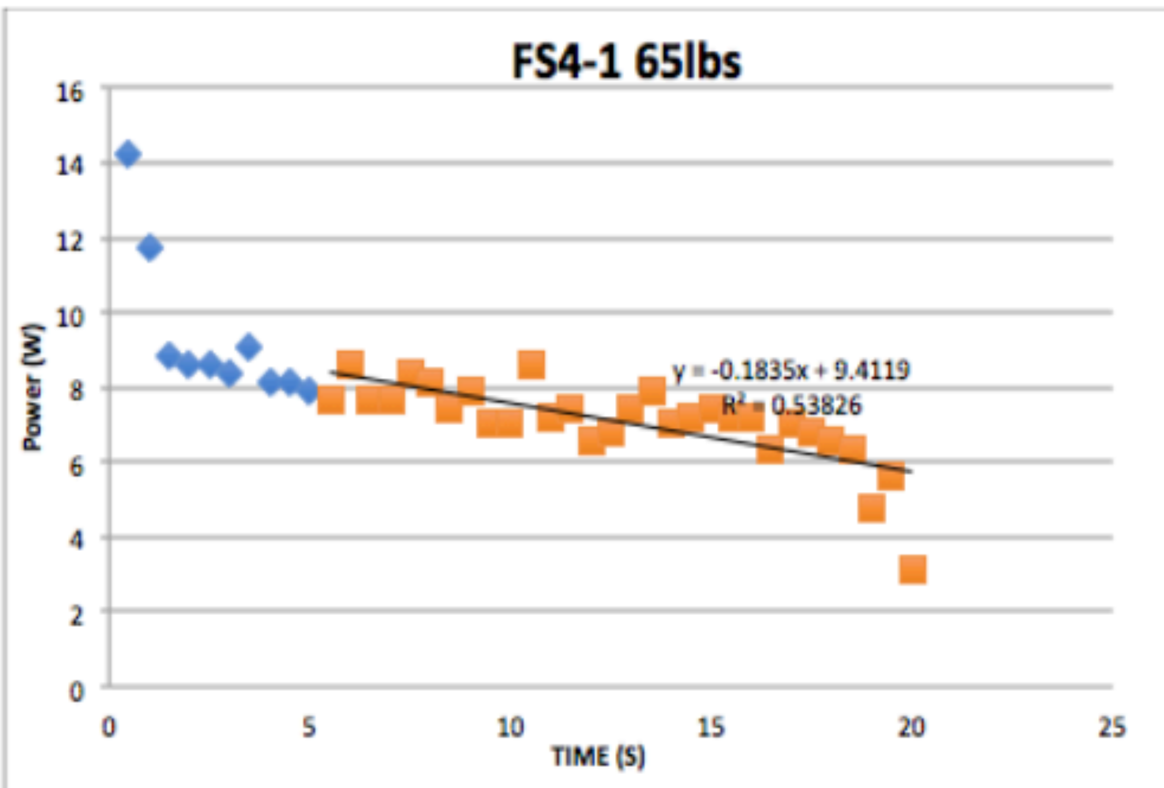

Figure 5. Example of Line of best fit in-water power decay

CHAPTER 3: RESULTS

Men vs Women

In-Water Test - Avg Power (W), Work/Stroke, Fatigue Index (slope)

Relative Power (W/kg) was compared between the men and women. Male participants pulled an average of 0.36 W/kg while women pulled 0.29 W/kg. Men exerted a higher relative power than women. Relative Power per stroke ($J \cdot stroke^{-1} \cdot kg^{-1}$) was analyzed to determine the stroke efficiency between males and females. Men pulled an average of .25 $J \cdot stroke^{-1} \cdot kg^{-1}$ while women pulled .18 $J \cdot stroke^{-1} \cdot kg^{-1}$. Men also have a higher relative power per stroke compared to women.

IN-Water Tables

Table 3. Relative Power (W/kg) for In-Water Test				
Men vs Women				
Female		Avg Power (W)	Kg	W/kg
FS4-1	Fem	18.80	63.30	0.2970
FS2-3	Fem	15.44	60.70	0.2544
FMD4-2	Fem	15.45	72.65	0.2127
FMD1-4	Fem	22.07	66.25	0.3331
FDS3-5	Fem	22.07	62.10	0.3554
			Avg	0.2905
Male		Avg Power (W)	Kg	W/kg
MMDF4-6	Male	32.99	79.20	0.4165
MMDIM4-8	Male	29.03	90.85	0.3195
MMDBr1-9	Male	24.65	73.80	0.3340
MMDBr3-10	Male	30.29	72.00	0.4207
MDF5-7	Male	32.07	98.40	0.3259
			Avg	0.3633

Table 4. Relative power per stroke(J·stroke1·kg-1) In-Water Test				
Men vs Women				
Female		J/Stroke	Kg	J·stroke^{-1}·kg^{-1}
FS4-1	Female	11.96	63.3	0.189
FS2-3	Female	10.47	60.7	0.172
FMD4-2	Female	9.23	72.7	0.127
FMD1-4	Female	13.92	66.3	0.210
FDS3-5	Female	11.65	62.1	0.188
			Avg	0.177
Male		J/Stroke	Kg	J·stroke^{-1}·kg^{-1}
MMDF4-6	Male	22.71	79.2	0.287
MMDIM4-8	Male	21.77	90.9	0.239
MMDBr1-9	Male	16.22	73.8	0.220
MMDBr3-10	Male	21.09	72.0	0.293
MDF5-7	Male	21.98	98.4	0.223
			Avg	0.252

Wingate (Men vs Women) –Relative Power & Fatigue

Relative power (W/kg) was compared between men and women for the Wingate test. Women biked 6.71 W/kg while the men biked 7.85 W/kg. Men biked at a higher power output per kilogram of body weight than women. The male participants fatigued at an average rate of 8.05 W/s, while the women fatigued at an average rate of 5.42 W/s on the Wingate test.

Table 5. Relative Power (W/kg) for Wingate Test				
Men vs Women				
Female		Avg Watts	Kg	Avg W/Kg
FS4-1	Female	426	63.3	6.73
FS2-3	Female	434	60.7	7.15
FMD4-2	Female	457	72.7	6.29
FMD1-4	Female	461	66.3	6.96
FDS3-5	Female	399	62.1	6.43
			Avg	6.71
Male		Avg Watts	Kg	Avg W/Kg
MMDF4-6	Male	631	79.2	7.97
MMDIM4-8	Male	673	90.9	7.41
MMDBr1-9	Male	577	73.8	7.82
MDF5-7	Male	808	98.4	8.21
			Avg	7.85

Table 6. Fatigue Index (W/s) for Wingate Test		
Men vs Women		
Women		Fatigue Index (W/s)
FS4-1	Fem	8.2
FS2-3	Fem	5.8
FMD4-2	Fem	5.9
FMD1-4	Fem	4.5
FDS3-5	Fem	2.7
	Average	5.4
Men		Fatigue Index (W/s)
MMDF4-6	Male	6.9
MMDIM4-8	Male	8.2
MMDBr1-9	Male	5.8
MDF5-7	Male	11.3
	Average	8.1

Sprint vs Distance vs Middle Distance

In-Water Test – Relative Power (W/kg), Work/Stroke (J), Fatigue Index (W/s) by Group

The average watts per kilogram of body weight were compared between sprinters, middle distance swimmers and distance swimmers. Sprinters pulled 0.28 W/kg, Middle Distance swimmers pulled 0.34 W/kg, and Distance Swimmers pulled 0.34 W/kg. Middle Distance swimmers and distance swimmers were the most powerful, followed by the sprinters. The sprinters had the lowest average relative power for the in-water test (0.28 W/kg). The power decay for the sprinters, middle distance swimmers, and distance swimmers had an average slope of 0.31, 0.59, and 0.91 W/s respectively. Distance swimmers had the highest fatigue rate, followed by the middle distance swimmers on the in-water test. Sprinters had the lowest fatigue rate on the in-water test.

Table 7. Relative Power (W/kg) for In-Water Test

Sprint vs Middle Distance vs Distance				
Sprinters		Avg Watts	Kg	W/kg
FS4-1	Female	18.80	63.3	0.2970
FS2-3	Female	15.44	60.7	0.2544
			Avg	0.2757
Middle Distance		Avg Watts	Kg	W/kg
FMD4-2	Female	15.45	72.7	0.2127
FMD1-4	Female	22.07	66.3	0.3331
MMDF4-6	Male	32.99	79.2	0.4165
MMDIM4-8	Male	29.03	90.9	0.3195
MMDBr1-9	Male	24.65	73.8	0.3340
MMDBr3-10	Male	30.29	72.0	0.4207
			Avg	0.3394
Distance		Avg Watts	Kg	W/kg
FDS3-5	Female	22.07	62.1	0.3554
MDF5-7	Male	32.07	98.4	0.3259
			Avg	0.3407

Table 8. Relative power per stroke (J·stroke1·kg-1) for In-Water Test				
Sprint vs Middle Distance vs Distance				
Sprinters		J/Stroke	Kg	J·stroke^{-1}·kg^{-1}
FS4-1	Female	11.96	63.3	0.1889
FS2-3	Female	10.47	60.7	0.1724
			Avg	0.1807
Middle Distance		J/Stroke	Kg	J/Stroke/Kg
FMD4-2	Female	09.23	72.7	0.1270
FMD1-4	Female	13.92	66.3	0.2101
MMDF4-6	Male	22.71	79.2	0.2867
MMDIM4-8	Male	21.77	90.9	0.2396
MMDBr1-9	Male	16.22	73.8	0.2198
MMDBr3-10	Male	21.09	72.0	0.2930
			Avg	0.2294
Distance		J/Stroke	Kg	J·stroke^{-1}·kg^{-1}
FDS3-5	Female	11.65	62.1	0.1875
MDF5-7	Male	21.98	98.4	0.2233
			Avg	0.2054

Wingate Test – Average Power, Fatigue Index by Group

Relative power was compared between men and women for the Wingate test. Sprinters biked 6.94 W/kg, middle distance swimmers biked 7.23 W/kg, and distance swimmers biked 7.32 W/kg. Distance swimmers had the highest relative power for the Wingate test, followed by middle distance swimmers. Sprinters had the lowest relative power. The fatigue rate (W/sec) for the sprinters, middle distance swimmers, and distance swimmers was 7.0, 6.3, and 7.0 W/sec respectively. Distance swimmers and sprinters had the highest fatigue rate on the Wingate test. Middle Distance Swimmers had the lowest fatigue rate on the Wingate test.

Table 9. Relative (W/kg) Power for Wingate Test				
Sprint vs Middle Distance vs Distance				
Sprint		Avg Watts	Kg	Relative Power (W/kg)
FS4-1	Female	426	63.3	6.73
FS2-3	Female	434	60.7	7.15
			Avg	6.94
Middle Distance		Avg Watts	Kg	Relative Power (W/kg)
FMD4-2	Female	457	72.7	6.29
FMD1-4	Female	461	66.3	6.96
MMDF4-6	Male	631	79.2	7.97
MMDIM4-8	Male	673	90.9	7.41
MMDBr1-9	Male	577	73.8	7.82
			Avg	7.29
Distance		Avg Watts	Kg	Relative Power (W/kg)
FDS3-5	Female	399	62.1	6.43
MDF5-7	Male	808	98.4	8.21
			Avg	7.32

Table 10. Power Decay W/s for Wingate by		
Sprint vs Middle Distance vs Distance		
Sprinters		Fatigue Index (W/s)
FS4-1	Fem	8.2
FS2-3	Fem	5.8
	Average	7.0
Middle Distance		Fatigue Index (W/s)
FMD4-2	Fem	5.9
FMD1-4	Fem	4.5
MMDF4-6	Male	6.9
MMDIM4-8	Male	8.2
MMDBr1-9	Male	5.8
	Avg	6.3
Distance		Fatigue Index (W/s)
FDS3-5	Fem	2.7
MDF5-7	Male	11.3
	Avg	7.0

Vertical Jump Test

The participants were ranked from highest to lowest vertical jump. The two female sprinters tied for the highest vertical jump (23.5 in). The female distance swimmer had the lowest vertical jump (15.5 in). The two middle distance swimmers scored above the distance swimmer and below the sprinters (18.0, 20.0 in). The male participants looked very different with a middle distance swimmer jumping the highest (30.0 in), followed by the distance swimmer (27.5 in). Two middle distance swimmers scored the lowest with jumps of 21.0, and 24.0 in.

Table 11. In Water & Vertical Jump Ranking

WOMEN

	Total Work (N)	Rank
(FS4-1)	502.39	1
(FMD4-2)	446.79	4
(FS2-3)	376.78	5
(FMD1-4)	487.24	3
(FDS3-5)	489.079	2

	Avg Work (N/s)	Rank
(FS4-1)	18.8	2
(FMD4-2)	15.45	5
(FS2-3)	15.44	4
(FMD1-4)	22.07	1
(FDS3-5)	17.79	3

	N/Stroke (effeciency)	Rank
(FS4-1)	11.96	2
(FMD4-2)	9.22	5
(FS2-3)	10.47	4
(FMD1-4)	13.92	1
(FDS3-5)	11.64	3

	Vertical Jump (in)	Rank
(FS4-1)	23.5	T1
(FMD4-2)	18	4
(FS2-3)	23.5	T1
(FMD1-4)	20	3
(FDS3-5)	15.5	5

MEN

	Total Work (N)	Rank
(DP-1)	734.31	3
(CH-2)	737.7	2
(RC-3)	595.14	4
(MP-4)	591.52	5
(HA-5)	739.96	1

	Avg Work (N/s)	Rank
(DP-1)	32.99	1
(CH-2)	32.07	2
(RC-3)	29.03	4
(MP-4)	24.65	5
(HA-5)	30.29	3

	N/Stroke (effeciency	Rank
(DP-1)	22.71	1
(CH-2)	21.96	2
(RC-3)	20.52	4
(MP-4)	16.22	5
(HA-5)	21.09	3

	Vertical Jump	Rank
(DP-1)	21	4
(CH-2)	27.5	2
(RC-3)	24	3
(MP-4)	30	1
(HA-5)		

Table 12. Wingate Ranking

	Mean Watts	Rank
(FS4-1)	426	4
(FMD4-2)	457	2
(FS2-3)	434	3
(FMD1-4)	461	1
(FDS3-5)	399	5

	Mean Watts	Rank
(DP-1)	631	3
(CH-2)	808	1
(RC-3)	673	2
(MP-4)	577	4
(HA-5)		

	Fatigue Index (W/s)	Rank
(FS4-1)	8.2	5
(FMD4-2)	5.9	4
(FS2-3)	5.8	3
(FMD1-4)	4.5	2
(FDS3-5)	2.7	1

	Fatigue Index	Rank
(DP-1)	6.9	2
(CH-2)	11.3	4
(RC-3)	8.2	3
(MP-4)	5.8	1
(HA-5)		

	Anaerobic Power (W/kg)	
(FS4-1)	8.6	1
(FMD4-2)	7.1	4
(FS2-3)	8.1	2
(FMD1-4)	7.6	3
(FDS3-5)	6.9	5

	Anaerobic Power	
(DP-1)	9	2
(CH-2)	9.3	1
(RC-3)	8.6	3
(MP-4)	8.3	4
(HA-5)		

	Total Work (J)	
(FS4-1)	20187.5	1
(FMD4-2)	13706.3	3
(FS2-3)	13030	4
(FMD1-4)	13840.6	2
(FDS3-5)	11969.7	5

	Total Work	
(DP-1)	10944	4
(CH-2)	24240.5	1
(RC-3)	20187.5	2
(MP-4)	17307	3
(HA-5)		

Correlation between Tests

Power Decay Wingate vs In-water

The male participants fatigue rate was 0.97 W/sec, while the women's fatigue rate was 0.31 W/sec on the in-water test. Similarly, the male participants fatigue rate was 8.05 W/sec, while the women's fatigue rate was 5.42 W/sec on the Wingate test. The male subjects fatigued more drastically on both the in-water and Wingate test.

The line of decay for the in-water test for the sprinters, middle distance swimmers, and distance swimmers had an average slope of 0.31, 0.59, and 0.91 W/sec respectively. The fatigue rate for the Sprinters, middle distance swimmers, and distance swimmers on the Wingate test was 7.0, 6.3, and 7.0 W/sec. The sprinters had the lowest fatigue rate for the in-water test, and tied for the highest fatigue rate on the Wingate test with the distance swimmers. The middle distance swimmers fatigued at a rate between the sprinters and distance swimmers on the in-water test, and fatigued the least on the Wingate test. The distance swimmers fatigued the most on the in-water test and tied with the sprinters for the highest fatigue during the Wingate test. Higher power decay on the Wingate is associated with higher power decay for the In-Water test ($r=0.75; p<0.005$) (see figure 7). Higher average power on the Wingate test is associated with higher power on the In-Water test ($r=0.89; p<0.005$) (see figure 8).

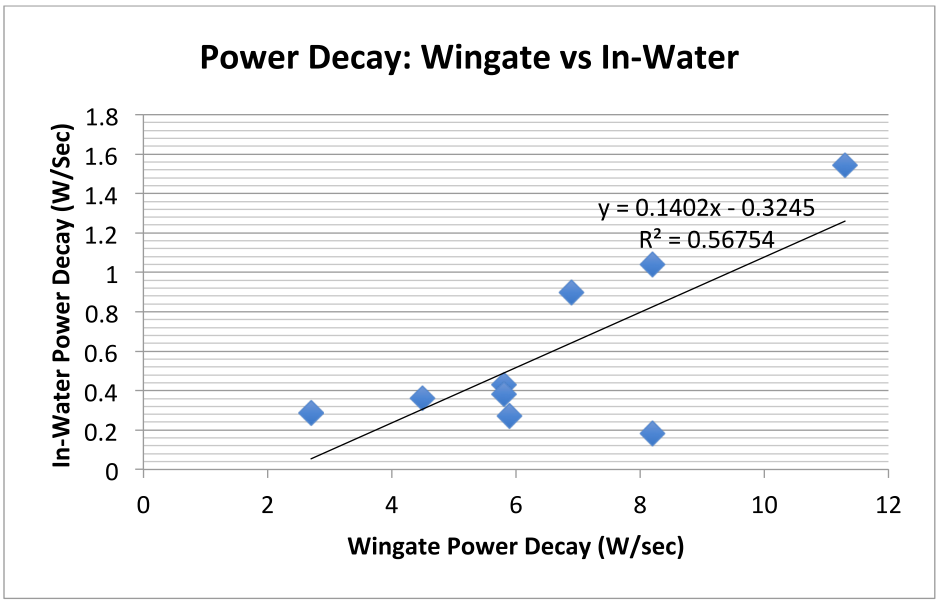

Figure 7. Power Decay: Wingate (W/Sec) vs In-Water (W/sec)

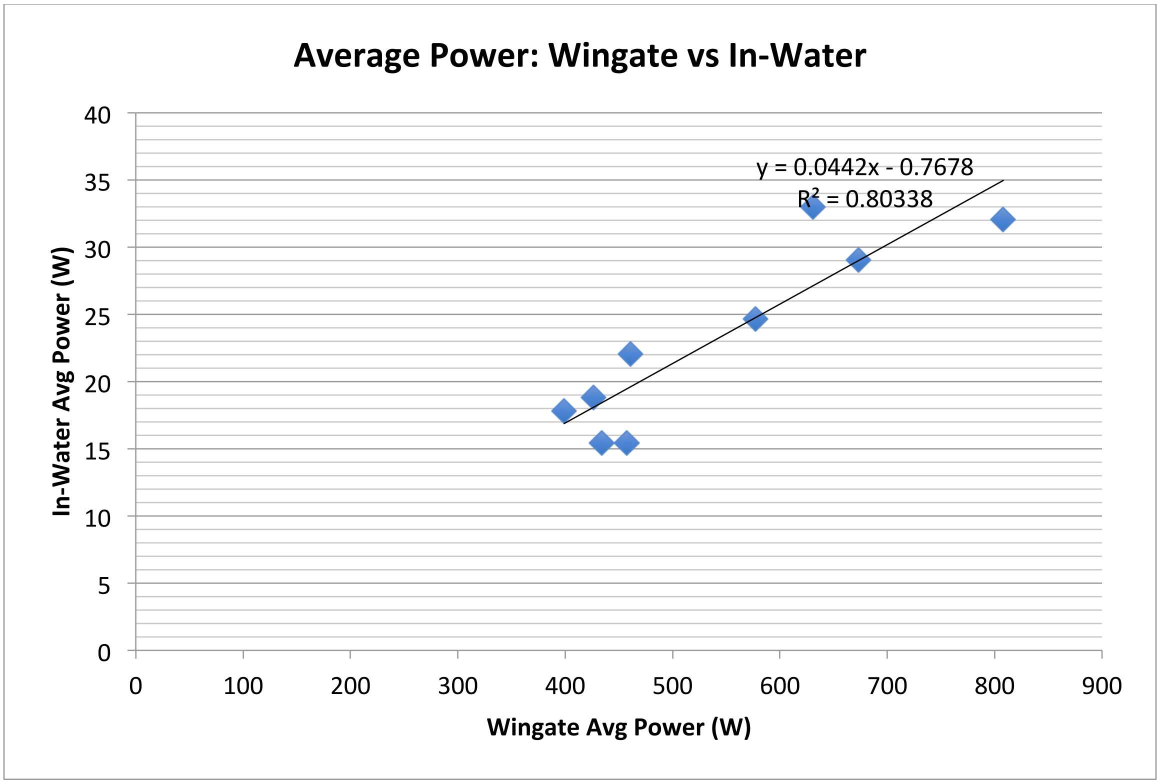

Figure 8. Wingate Avg Power (W) vs In-water Avg Power (W)

Vertical Jump Test vs In-Water Test

The vertical jump relative power for each participant was compared to both In-water peak power (W) and in-water relative power (W/kg). Higher vertical jump relative power (W) is associated with higher peak power (W) for the In-Water test ($r=0.72; p<0.005$) (see figure 9). Higher power on the vertical jump (W) is associated with higher power on the In-Water test ($r=0.74; p<0.005$) (see figure 10).

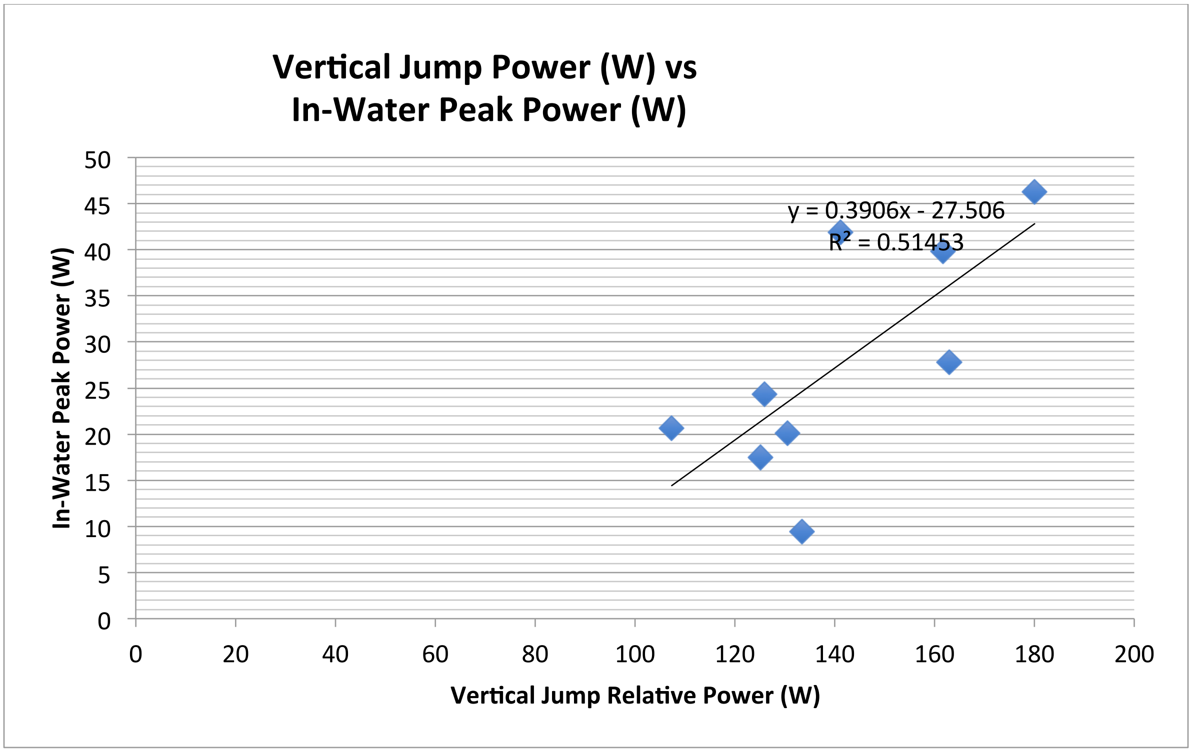

Figure 9. Vertical Jump Relative Power (W) vs In Water Peak Power (W)

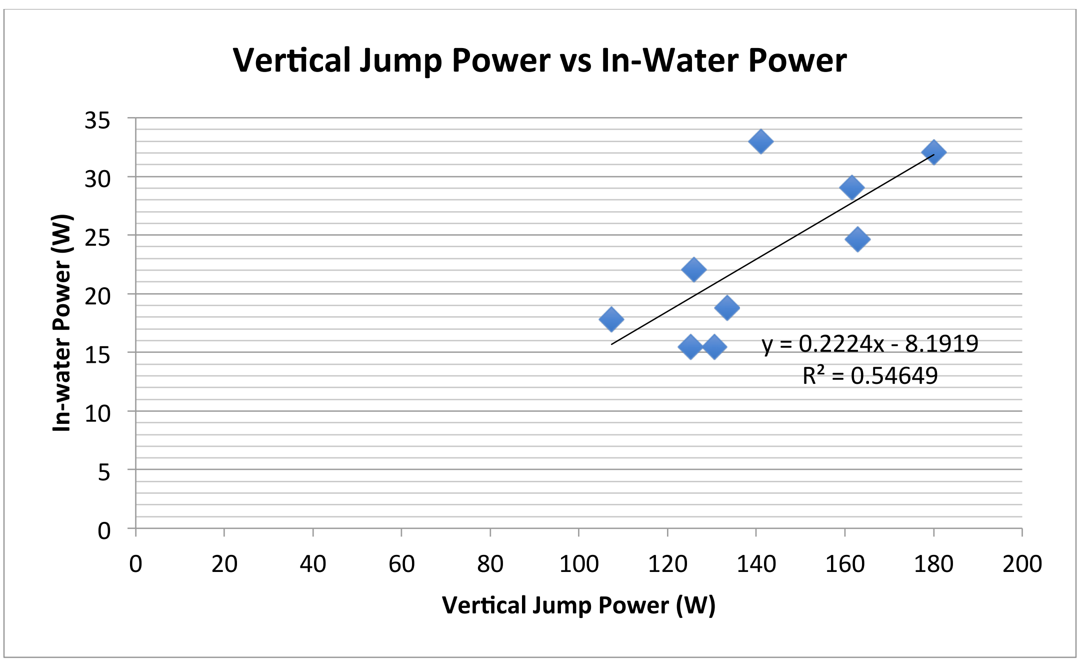

Figure 10. Vertical Jump Relative Power (W) vs In Water Relative Power (W/kg)

Table 13. Power Decay W/s In-Water vs Wingate			
Sprint vs Middle Distance vs Distance			
Sprinters		Slope (In-Water)	Fatigue Index (Wingate)
FS4-1	Fem	0.184	8.2
FS2-3	Fem	0.431	5.8
Average	Average	0.307	7.0
Middle Distance		Slope (In-Water)	Fatigue Index (Wingate
FMD4-2	Fem	0.270	5.9
FMD1-4	Fem	0.362	4.5
MMDF4-6	Male	0.899	6.9
MMDIM4-8	Male	1.041	8.2
MMDBr1-9	Male	0.380	5.8
Average		0.590	6.3
Distance		Slope (In-Water)	Fatigue Index (Wingate
FDS3-5	Fem	0.286	2.7
MDF5-7	Male	1.542	11.3
Average		0.914	7.0

Table 14. Fatigue Index (W/s) In-Water vs Wingate Test			
Men vs Women			
Women		Slope (In-Water)	Fatigue Index (W/s)
FS4-1	Fem	-0.1835	8.2
FS2-3	Fem	-0.4305	5.8
FMD4-2	Fem	-0.2704	5.9
FMD1-4	Fem	-0.3615	4.5
FDS3-5	Fem	-0.2856	2.7
	Average	-0.3063	5.42
Men		Slope (In-Water)	Fatigue Index (W/s)
MMDF4-6	Male	-0.8988	6.9
MMDIM4-8	Male	-1.0411	8.2
MMDBr1-9	Male	-0.3803	5.8
MDF5-7	Male	-1.5423	11.3
	Average	-0.965625	8.05

Hypothesis 1)

The data did not reflect the first hypothesis that sprinters will have a higher average power output and decelerate faster than middle distance and distance swimmers. The sprinters had the lowest power output per kilogram of body weight for both the in-water test and the Wingate test. The middle distance and distance swimmers averaged less than 1 % difference from each other on both the Wingate and In-water test (0.3394 and 0.3406 W/kg in-water) and (7.288 and 7.318 W/kg Wingate). The sprinters tied with the distance swimmers for the most power decay during the Wingate test. The sprinters had the least extreme slope of power decay for the in-water test.

Hypothesis 2)

The female sprinters did have the highest vertical jump followed by the middle distance and distance swimmers. The women's rank for relative power was calculated by the Lewis Equation and yielded the same results. The male participants' results did not align with the hypothesis neatly like the women's. The distance swimmer scored the second highest on the vertical jump test with one middle distance swimmer scoring the highest while the other two middle distance swimmers scored the lowest. The distance swimmer was ranked the highest with regards to relative power, followed by the middle distance swimmers.

Hypothesis 3)

The data supported the hypothesis that men pulled and biked with higher average power and power per stroke than women per kilogram of bodyweight. The male participants biked an average of 7.85 W/kg and the women biked 6.71 W/kg for the Wingate test. The female participants pulled 0.29 W/kg and 0.18 $J \cdot stroke^{-1} \cdot kg^{-1}$ while the men pulled .36 W/kg and

.25 J·stroke^{-1}·kg^{-1} during the in-water test. The men were more powerful per second and per stroke during the in-water test.

Hypothesis 4)

The data supported the hypothesis that women's power curves will have less extreme slope than men's. The female participants showed less extreme power decay on both the in-water test and Wingate test. The male participants lost power at a rate of 8.05 W/s for the Wingate test and 0.97 W/s on the in-water test. The female participants lost power at a rate of 5.42 W/s on the Wingate test and 0.31 W/s during the in-water test. The data shows that women are more adept at holding on to power on both land and water when performing a maximal test.

Hypothesis 5)

The participants rank for fatigue index on the Wingate test and deceleration during the in-water test did not correlate for both sexes. Female Sprinter FS4-1 had the least amount of power decay for the in-water test and the highest fatigue index on the Wingate test. Female participant FMD4-2 had the least extreme slope (0.27 W/sec) other than FS4-1, while having the second highest Fatigue index on the Wingate test (5.90 W/sec). The men, however had the same rankings on both the Wingate test and the in-water test. The distance swimmer MDF5-7 showed the most fatigue on the Wingate test (11.3 W/s) and the in-water test (1.54 W/s). The male participants had the same rank for fatigue index on the Wingate and power decay for the in-water test while the women did not.

CHAPTER 4: Discussion

The purpose of this study was to standardize a way to test power in the water that is relatable to the results of the Wingate power test. The data supports the claim: Higher power decay and peak power on the Wingate is associated with higher power decay and peak power for the In-Water test ($r=0.75;p<.005$). The first hypothesis was that sprinters would perform at a higher power output and decelerate faster than middle distance and distance swimmers. The power output was calculated in watts per second on both the in-water test and Wingate test. The results showed that that the sprinters' power output was less than the middle-distance swimmers and distance swimmers per kilogram of body weight. The male participants scored higher for power output for both the Wingate test and the in-water test. The fact that there were no male sprinters that volunteered for the project skewed the overall sprinter power output. In order to make claims in which one group performs better on a certain test, there must be representatives for each group from each sex. The results for the power decay were similarly affected by the study population. The sprinters had less extreme slopes on the in-water power decay than the middle distance and distance swimmers. Men showed higher values of power decay on both the in-water test and Wingate test. The fact that there were no male sprinters also skewed the power decay data by group.

The second hypothesis that sprinters would have a higher vertical jump than middle distance and distance swimmers was analyzed separately by sex, due to the fact that there were no males representing the sprint group. The female vertical jump values followed this trend exactly with the two sprinters tying for 1st, followed by the two middle distance swimmers and the distance swimmer jumping the least. The male distance swimmer jumped the second most. The middle-distance swimmer who performed the best has some sprint tendencies. The distance swimmer that performed second best was the most elite of the athletes in the experiment. The fact that vertical jump is an indicator of athleticism suggests that even if a swimmer performs better at longer distances, he or she may have explosive tendencies greater than that of other athletes that may perform sprint events. The female athletes were all similar in elite status, suggesting that when talent or athleticism is equal, athletes that race shorter events will have more explosive characteristics. Female participants averaged 20.1 inches and male participants averaged 26.5 inches.

The hypothesis that men had higher average power and power per stroke than women was reflected in the data. In order to minimize the effects of body weight, the power output was divided by the subject's weight in kilograms. Men pulled 19 % more watts per kilogram of body weight (0.29 vs 0.36 W/kg) and had 30 % more power per stroke than the women (0.25 vs 0.18 W/kg) during the in-water test.

Women's power curves had less extreme slopes for both the in-water test and Wingate test. The fact that women maintain their max power better than men is supported by the data. During the Wingate test, the women's rate of decay was 33 % lower than the men's (5.42 vs 8.05 W/s). The female participants rate of decay for the in-water test was 68 % lower than the men's rate of decay (0.31 vs 0.97 W/s).

Limitations

The primary limitation was due to the diversity and sample size of the subject population. In order to make claims about characteristics of different training groups and sex, a much larger pool of subjects should be recruited. Anatomical differences between men and women challenged the validity of the comparison between the sexes. The lack of male sprinter subjects skewed the data by group and makes it difficult to state findings by group. Outliers have a large effect on the data with such a small sample size. In order to increase the validity of the data, a pool of 20 or more subjects should be recruited that has equal distribution across groups and sex. The challenge of finding elite collegiate athletes that are willing to participate in studies is a limiting factor.

Strengths

Strengths of the experiment are the definitive nature of the male vs female data. Even in a small population, conclusions could be drawn from the data when looking at differences between sexes. The validity of the male vs female data could be achieved by group with a much larger population with equal representation from sprint, middle distance and distance swimmers. There is strength in knowing that each athlete is individual, and although many of the athletes follow certain trends, there will always be outliers that require different training in order to be successful.

Considerations for Future Research

The in-water power test should be analyzed on a larger scale with more participants. Perhaps different schools and or teams could collaborate and share data to increase the study population and increase understanding of the general trends that elite athletes elicit. Dr. Neil Johannsen of LSU has expressed interest in collecting heart rate and lactate data to increase our understanding of the physiological processes utilized during the maximal test. Skin folds, Dexa, or bod pod data could be collected in the future to correlate overall body composition with performance. The test should be performed multiple times a season in order to track progress.

CHAPTER 5: Conclusion

The in-water test is an excellent way to track the power of an elite swimmer throughout the season. The Wingate test and In-water test show similar results when comparing men and women, although there are individual differences that must be considered when analyzing athletes by group. Land power and water power are two different elements that do not always correlate for each athlete. Further research with a larger pool of participants will yield more information about the application of the in-water test as a “gold-standard” power test to compare to the Wingate test. The in-water power test is a reliable way to test the power of athletes in the water and should be compared to athletic performance to better understand the training program of elite swimmers.

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